DESIGN OF BUTTON BEAM POSITION MONITOR FOR THE BRAZILIAN SYNCHROTRON LIGHT SOURCE

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Abstract

We present the electrical and mechanical design of a button beam position monitor (BPM) recently developed and installed in the UVX electron storage ring at the Brazilian Synchrotron Light Laboratory (LNLS). The first characterization results will also be presented. This development started when we observed strong correlation between false stripline BPM readings and the external temperature of this BPM. Simulations indicate that the temperature gradient in the BPM body can cause deformations that could explain the false readings in some BPMs. The small dimension of the button compared to the stripline and the better thermal isolation between the button and the BPM body should contribute to minimize this problem.

INTRODUCTION

The LNLS 93-meter long 1.37-GeV electron storage ring has 24 BPMs distributed along its 6 superperiods. Currently only one BPM that is installed in the injection straight section is a button BPM, all the others are 6-cm long stripline BPMs.

In the last years false BPM readings have been observed at every shift for a given beam current in a few BPMs. Figure 1 shows an example.

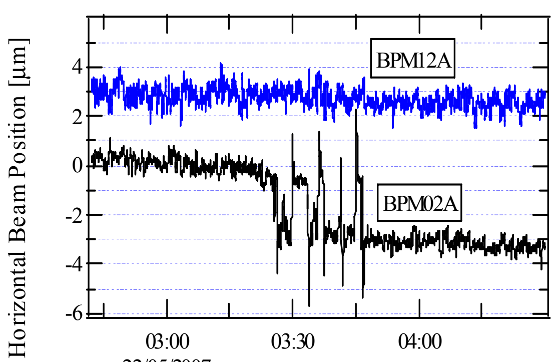

Figure 1: False BPM reading with daily regularity that appears always in the same stripline BPM when the beam current reaches a specific value. So far we have observed three BPMs with this behavior. The current in which the problem occurs is different for each BPM.

In 2006 we performed a set of experiments and simulations [1] that indicate that the problem is due to an uneven temperature distribution inside the stripline BPM. Figure 2 shows a numerical simulation emphasizing the mechanical asymmetries of the BPM body due the synchrotron radiation heating.

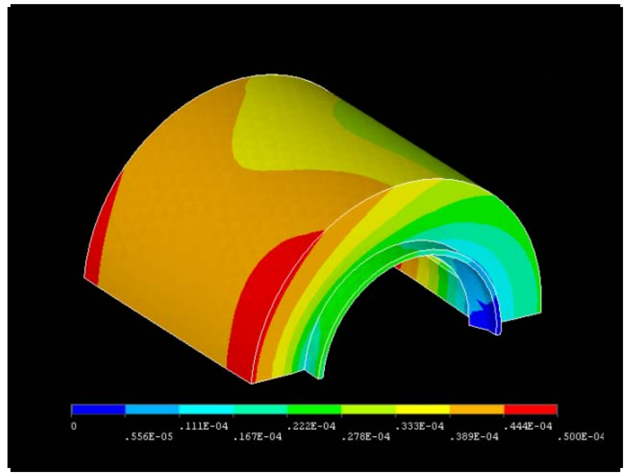

Figure 2: Numerical simulation showing mechanical deformations on the BPM caused by temperature differences along the 316L stainless steel BPM body. Temperatures as high as 300 ºC in the BPM areas near the beam plane can cause 100-µm asymmetries in the striplines. Note that the striplines are free in one extremity making the heat exchange more difficult in this region.

We concluded that these internal thermal gradients are causing the unphysical BPMs' readings shown in figure 1.

BUTTON BPM DESIGN

In order to solve or minimize the problem described above, a project to design and build a button BPM prototype at LNLS was started. A button BPM consists of four round discs (or buttons) mounted flush with the vacuum chamber symmetrically spaced and electrically isolated from the vacuum chamber. The button geometry, the axial gap between the button and the vacuum chamber and the geometry of vacuum feed-through that connects the button to the BPM coaxial connector determine the performance of the BPM. The transfer impedance [2] that describes the sensitivity of the button is given by (1):

$$Z_b = \phi \, R_0 \left(\frac{\omega 1}{\omega 2} \right) \frac{j\omega j/\omega 1}{1 + j\omega/\omega 1} \qquad (1)$$

Where $\omega 1 = 1/R_0C_b$; $\omega 2 = c/2r$ is the inverse of the electrode traversal time; C_b is the button capacitance to ground; r is the button radius; c is the speed of light; φ is the coverage factor = r/4b and b is the beam pipe radius (30 mm in the LNLS storage ring). R_0 is the characteristic impedance of the coaxial cable that connects the button to the load resistor. The modulus of the transfer impedance is given by (2):

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$$|Z_b(\omega)| = \phi R_0 \left(\frac{\omega 1}{\omega 2}\right) \frac{\omega / \omega 1}{\sqrt{1+(\omega/\omega 1)^2}} \quad (2)$$

Rewriting equation (2) we see that the transfer impedance is strongly affected by the button radius and not affected by the button capacitance in the MHz frequency region, since the button capacitance of a usual BPM is smaller than 10 pF and R_0 is 50 Ω in almost all applications:

$$|Z_b(\omega)| = \frac{R_0}{2\,b\,c} \frac{\omega\, r^2}{\sqrt{1+(\omega\, R_0\, C_b)^2}} \quad (3)$$

The button capacitance C_b can be calculated as the coaxial capacitance formed by the round disc and the beam pipe. The thicker the disc the higher the capacitance, as seen in equation (4):

$$C_b = \frac{2\,\pi\,\varepsilon_0}{\ln\left(\frac{r+w}{r}\right)} L \quad (4)$$

Where ε_0 is the dielectric permittivity of free space, L is the length of the short coaxial formed and w is the gap between the disc and the vacuum chamber (annular cut).

Equation (3) shows that the transfer impedance scales with r^2 and the equation (5) shows that the coupling impedance scales with r^4. This limits the button radius:

$$Z_{coup} = \phi\left(\frac{\omega 1}{\omega 2}\right) Z_b \quad (5)$$

The LNLS button BPM will be used primarily for closed orbit measurements that currently use Bergoz tuned electronics; therefore the transfer impedance is only important at the RF frequency, 476 MHz. Through Eq. (5), we see that the button capacitance can be used to reduce the coupling impedance, since higher capacitances do not change the transfer impedance at low frequencies (see Eq. 3). Figure 3 shows the transfer impedance calculated for some button geometries.

Equation (5) only describes the coupling impedance related with the fields that contribute to the signal formation. The wavelength of the first parasitic mode related to the button geometry [2] is given by (6):

$$\lambda_1 = 2\pi\left(\frac{2r+w}{2}\right) \quad (6)$$

Finally, for wavelengths greater than the annular cut, there is an additional (and in our case, dominant) contribution for the coupling impedance [3]:

$$Z_{coup\_cut} = -j\,\frac{Z_0\,\omega\,(r+w)^3}{8\,c\,b^2\{\ln[32(r+w)/w]-2\}} \quad (7)$$

Where Z_0 is the free space impedance.

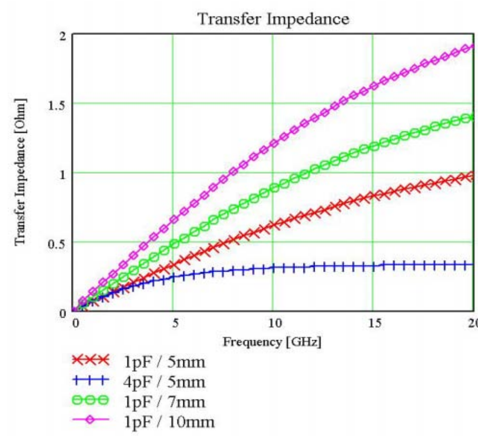

Figure 3: Modulus of the transfer impedance calculated for some values of button capacitance and button radius. In the low frequency region the button capacitance does not affect the transfer impedance, but a small increase in the radius impacts significantly the transfer impedance value.

The geometry chosen for the LNLS button was: annular cut = 1 mm; button radius = 5 mm, button thickness = 3 mm, resulting in a calculated button capacitance of 1 pF. Smaller gap would be preferable, but the manual soldering process put the 1 mm minimum value due alignment limitations. The calculated transfer impedance at RF frequency is 33 mΩ and calculated the coupling impedance calculated with (7) at the RF frequency is about –3 i mΩ. The LNLS 3 cm (FWHM) electron bunch roll-off is about 5 GHz, the modulus of the coupling impedance calculated with (5) at this frequency is smaller than 1 mΩ and the λ1 wavelength calculated with (6) is 8.7 GHz, far enough from the bunch bandwidth.

The buttons used in the new BPM were totally produced in the LNLS facility. The ceramic used for brazing the button was Alumina (AL_2O_3) acquired form Saint Gobain (France) and the button electrode material used was kovar. A commercial eutectic joint, the Ag-28Cu, was used as addition metal.

Several machining and brazing tests have been carried out to get good mechanical repeatability and good vacuum characteristics. Figure 4 illustrates the mechanical design of the button and shows a picture of the button before soldering in the BPM body.

Figure 4: Button mechanical design and button after complete mounting (before soldering in the BPM body). The cone above the button creates a 50 Ω tapered transmission line with the BPM wall.

The calculated capacitance of the LNLS button is about 1 pF. Although we do not have the most appropriated hardware to perform precise TDR (Time Domain Reflectometry) analysis, some TDR measurements carried out indicates that the capacitance of the buttons is grater than 4 pF. The difference from the calculated value is probably due to the vacuum feed-trough and the electrode brazing contribution to the total capacitance.

Initially we produced and installed two button BPMs in the elliptically polarized undulator (EPU) [4] straight section. Now this section has two stripline and two button-type BPMs.

The mechanical gain and offset of the BPMs were characterized with the stretched wire method in an automated bench. The results showed similar gains and offsets compared to the stripline BPMs.

The 27 dB attenuators that condition the signals from the stripline BPMs to the Bergoz MX-BPM modules were replaced with 4 dB attenuators for the two new button BPMs.

FIRST RESULTS

The noise level of the position readings of the four BPMs in the undulator straight section is practically the same, smaller than 1 μm RMS up to 1 Hz.

The power level measured at the RF frequency indicated a transfer impedance of about 100 mΩ. We do not know the reason for this factor three discrepancy.

Figure 5 shows the signal from one button measured with a low current single-bunch in the storage ring.

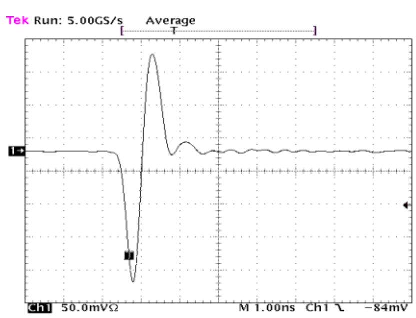

Figure 5: Button signal with a 2.5 mA single-bunch in the storage ring. The signal symmetry and the amplitude of the reflections indicate that the impedance matching provided by the cone above the button is efficient.

There are no problematic stripline BPMs in the EPU straight section. To compare the performance of the BPMs (stripline versus button) under mechanical stress caused by temperature distribution, a test was performed heating only a small part of the BPMs' body around the beam plane with baking strips simulating heating by synchrotron radiation. The test was performed with the two BPMs located at the end of the EPU straight section. In principle these BPMs are not affected by the synchrotron radiation from the upstream dipole. During the test the orbit feedback was off and the EPU was open.

With 250 mA in the storage ring @ 1.37 GeV, we heated both BPM bodies up to 100 ºC (external temperature near the baking strips). Several hours later, after temperature stabilization, we turned-off the heating and observed the behavior of both BPM readings. Figure 6 shows the results.

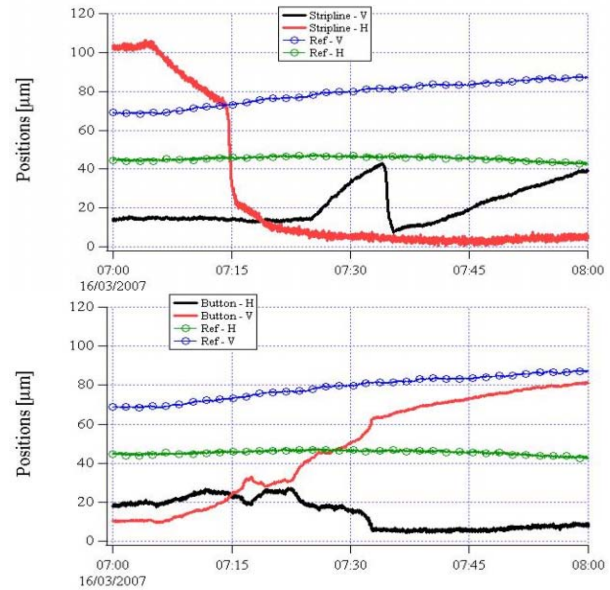

Figure 6: External heating experiment with a stripline and a button BPM. In both graphs there are reference readings from one BPM that had not been heated.

Both horizontal and vertical readings of the stripline BPM show fast changes that indicate mechanical distortion of the striplines. This result was obtained with external heating. The BPMs in the ring, which are heated by synchrotron radiation, experience much more severe temperature distributions.

CONCLUSIONS

The new button-type BPM design based on [2] and [3] was presented. The new BPMs were installed in the storage ring and the comparative test performed indicated that these BPMs will not suffer from distortion problems, as some stripline BPMs. Replacing straight section BPMs is a very complicated operation. It involves long shutdown periods and difficult vacuum recovery; therefore we are trying alternative solutions, such as better cooling of the vacuum chamber upstream, of the affected BPMs.

REFERENCES

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